23. LOW-G PAYLOAD PLACEMENT CONSTRAINTS FOR SPACE STATION

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ABSTRACT

Payloads onboard the Space Station will be subjected to a steady state acceleration level dominated by gravity gradient and aerodynamic drag forces. The g-level due to gravity gradient forces depends on the payload location relative to the center of mass, whereas the g-level due to aerodynamic drag may be assumed nearly constant throughout the Space Station. The vector of acceleration due to aerodynamic drag can always be broken down into three orthogonal components, in the direction opposite to the velocity vector, along the local vertical, and perpendicular to the orbit plane. It will be shown that the gravity gradient term has two components, which are orthogonal to one another. One component is along the local vertical and the other is perpendicular to the orbit plane. Thus, the combination of all components form an orthogonal triad of vectors. This paper will address the payload location constraints to satisfy the requirements of 1 micro-g. The permissible locations are within an open-ended tube having an elliptical cross section, which is aligned with the velocity vector and centered on the system center of mass.

INTRODUCTION

Payloads onboard the Space Station are subjected to a steady state g-level dominated by gravity gradient and aerodynamic drag forces (Figure 1). The g-level due to gravity gradient depends on the payload location relative to the center of mass, whereas the g-level due to aerodynamic drag is constant throughout the Space Station. This briefing addresses the payload location constraints to satisfy a requirement of 1 micro-g maximum acceleration.

Additional disturbances to the microgravity environment, such as the accelerations expected during reboost will also be presented.

ACCELEROMETER EQUATION/ASSUMPTIONS

An accelerometer senses the vector sum of all gravitational, inertial, and external accelerations. Or stated in terms of forces, the accelerometer senses the vector sum of all gravitational, inertial, and external forces.

The acceleration equation (Figure 2) with the station in a circular orbit and in a local vertical orientation contains both an in-the-orbit plane term and an out-of-the-orbit plane term.

The g-level for a payload at a specified distance from the center of mass has one gravity gradient component along the local vertical and another perpendicular to the orbit plane.

The permissible microgravity payload locations are within an open-ended tube having an elliptical cross section. This elliptical boundary constraint is aligned with the velocity vector and centered on the trajectory of the system center of mass.

ONE MICRO-G BOUNDARY CONSTRAINT WITHOUT AERODYNAMIC DRAG EFFECT

The payload location constraint for a maximum acceleration level of one micro-g and a 220 nm circular orbit is shown in Figure 3. The velocity vector is into the paper. Since the boundary is determined only by distance from the center of mass it is independent of the station configuration.

To obtain boundaries for g-levels other than one micro-g, it is only necessary to scale both axes by the same amount. The curve will always be an ellipse with a three to one ratio between major and minor axes, with the tighter constraint being in the axis aligned with the local vertical.

<u>Ex</u>: For a 10 μg requirement,
Major axis = 10 (major axis for 1 μg) = 10 (50.4 ft) = 504 ft
Minor axis = 10 (minor axis for 1 μg) = 10 (16.8 ft) = 168 ft

<u>ACCELEROMETER EQUATION/ASSUMPTIONS</u> (CONTINUED)

IN TERMS OF STATION BODY AXES ($\underline{u} = \underline{u}_z$, $\underline{u}_o = \underline{u}_y$) EQUATION (2) BECOMES,

$$\underline{A} = \Omega_o^2 \, y \, \underline{u}_y - 3\Omega_o^2 \, z \, \underline{u}_z$$

EXPRESSING THE ACCELERATION LEVEL IN UNITS OF G'S,

$$\underline{g} = \frac{\Omega_o^2}{g_o} \, y \, \underline{u}_y - 3 \, \frac{\Omega_o^2}{g_o} \, z \, \underline{u}_z$$

THE ABOVE COEFFICIENT IS CALCULATED AS,

$$\frac{\Omega_o^2}{g_o} = \frac{1/R_o}{(1+h/R_o)^3}$$

WHERE, R_o IS THE EARTH'S RADIUS

h IS THE ORBIT ALTITUDE

THE STRUCTURE OF THE ACCELERATION EQUATION IS,

$$\underline{g} = \frac{y}{\alpha} \, \underline{u}_y - \frac{z}{\beta} \, \underline{u}_z$$

WHERE, $\alpha = \left(\frac{\Omega_o^2}{g_o}\right)^{-1}$ AND $\beta = \frac{\alpha}{3}$

EXPRESSING THE MAGNITUDE ONLY,

$$g^2 = \frac{y^2}{\alpha^2} + \frac{z^2}{\beta^2}$$

THIS EQUATION FOR AN ELLIPSE IN THE Y-Z PLANE DEFINES THE ACCELERATION BOUNDARY CONSTRAINT IMPOSED BY GRAVITY GRADIENT FORCES.

THE DESIRED MAXIMUM G-LEVEL IS USED FOR THE VARIABLE g.

FIGURE 2. (Concluded)

It is important to realize that knowledge of the center of mass location may be no better than a 1-ft-diameter sphere, even with good bookkeeping of fuel usage, payload repositioning, etc. Thus, it appears that locating payloads to receive less than 10^{-6} g acceleration may be unrealistic on the Space Station. Active control or movement of the center of mass will also be difficult after the operational configuration is established. A rough calculation shows that it would require approximately 33,000 lbm added to the far end of the station to move the center of mass one truss cube (16.4 ft).

VARIATION OF ALPHA AND BETA COEFFICIENTS WITH ALTITUDE

The α (semimajor axis) and β (semiminor axis) coefficients vary almost linearly, but very slightly, with altitude (Figure 4).

Previous plot was arbitrarily calculated for a 220 nm orbit since actual operational altitude is uncertain and could be a variable, constant density altitude profile.

AERODYNAMIC DRAG EFFECT

The vector of acceleration due to aerodynamic drag can always be resolved into three orthogonal components, in the direction opposite to the velocity vector, along the local vertical, and perpendicular to the orbit plane. It is assumed to be uniform over the station structure.

The effect of aerodynamic drag on the boundary constraints is to reduce the dimensions of the ellipse. In the limiting case, as the g-level due to aero approaches the maximum requirement level, the ellipse contracts down to a point. There is no further meaning to boundary constraints if the aerodynamic contribution exceeds the requirement level.

ONE MICRO-G BOUNDARY CONSTRAINTS FOR SEVERAL VALUES OF AERODYNAMIC DRAG

The open-ended elliptical constraints for a requirement of one micro-g total acceleration are shown for aerodynamic drag components of 0., 0.25, 0.5, and 0.75 micro-g's, assuming that the drag force acts

only in the direction of the velocity vector. It can be seen that the size of the ellipse decreases rapidly with increasing aerodynamic drag (Figure 5).

Actually, the vector of the drag force will always have components in all three orthogonal directions; their magnitudes change periodically during each orbit because of the periodic attitude change of the solar panels. The "ellipses" of constraint, therefore, will become non-symmetrical contour lines under the influence of aerodynamic drag.

ACCELERATION DUE TO RCS FIRINGS DURING REBOOST

The Space Station will need to be reboosted approximately every 90 days during normal operation. For the 9-ft truss dual keel configuration, six (+X) 25-lb engines are on nominally with the appropriate engines off-modulated for attitude control.

Figure 6 shows the X acceleration profile as sensed near the module cluster during a representative portion of the reboost burn. A rigid station is assumed. The accelerations in the Y and Z directions are approximately one order of magnitude smaller than those in the X (flight path) direction.

ADDITIONAL "STEADY STATE" DISTURBANCES

Although the gravity gradient and aerodynamic drag are the dominant "steady state" disturbances, several other unavoidable disturbances will be affecting the acceleration environment (Figure 7). These include crew motion, rotating machinery, fluid loops, and momentum management maneuvers.

Larger, infrequent disturbances such as reboost, shuttle and OMV docking, RMS operation, and others will dictate an interruption of sensitive microgravity payloads.

Question:
Ken Demel, NASA/Johnson Space Center: On these assumptions of constant drag, we have done some computations with rotating the panels through
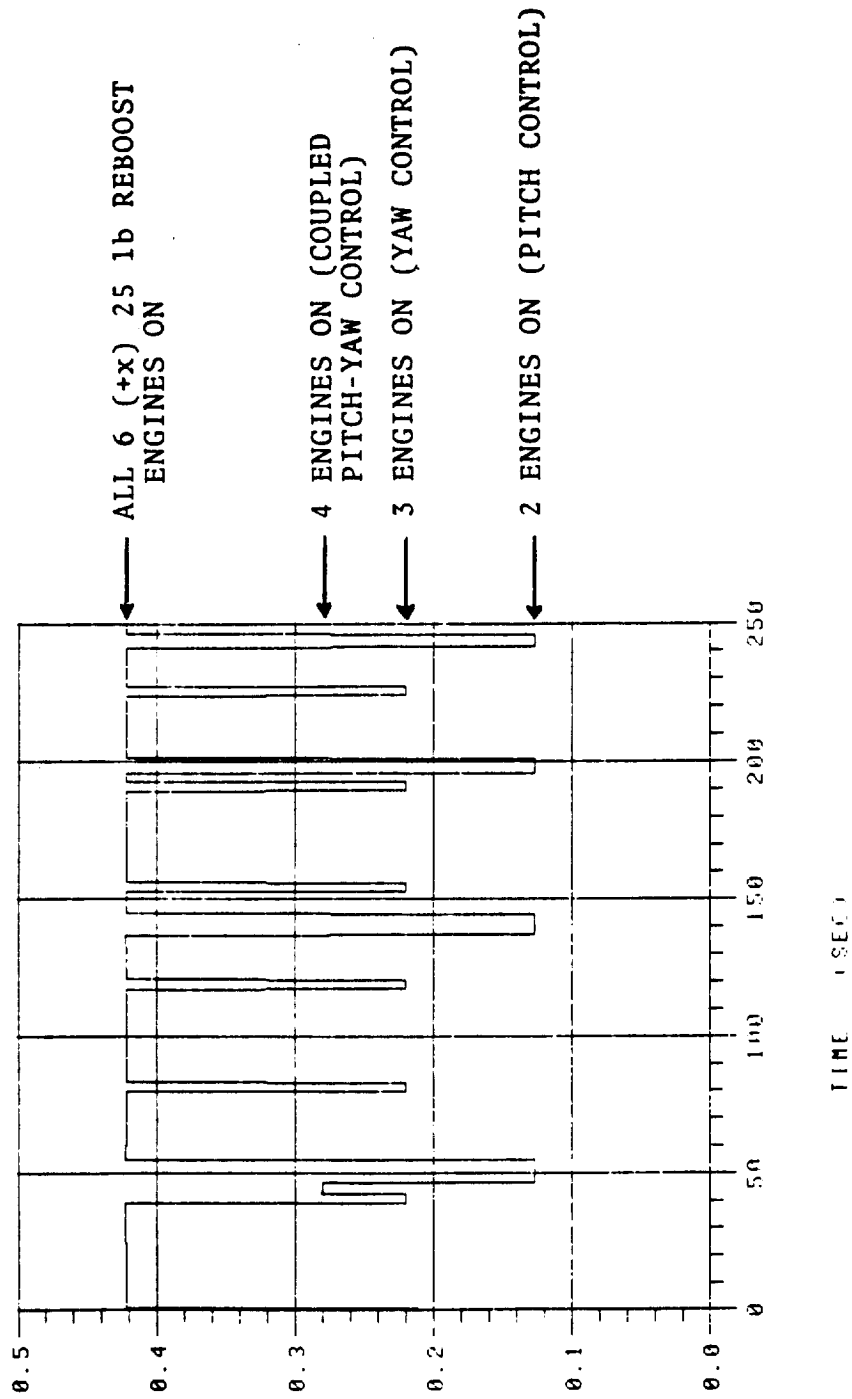
FIGURE 6.

the diurnal bulge as you fly through an orbit. The minimum drag in the orbit is about a twentieth of a micro-g and the maximum in the orbit is about a half of a micro-g. So, when you vectorially add that to the gravity gradient form you wind up with a fan of vectors that is rotating. The vectorial resultant of the two is rotating through about 20 to 25 degrees. I don't know whether people have really looked at it in that detail, but up will not always be in the same direction as you go though the orbit. Some of these assumptions of constant drag tell you what is going to happen to your altitude but they don't tell you anything about what is happening over about a 10- to 15-minute period and if a particular crystal growth is sensitive to the symmetry condition, that rotation is really going to degrade it over several hours. So, I'd like to see the actual drag profiles through an orbit taken into account.

Carpenter: Of course I guess you are going to have to design your experiment to withstand the worst case aerodynamic drag.

Demel: But we might want to look at those effects as they really occur and not assume constant effects, and maybe that drives us to requiring drag makeup as we go.

Ed Bergmann, C.S. Draper Laboratory: You assumed that the space station was in a local vertical attitude and you threw out some terms because it was maintaining that attitude. The shuttle when it holds attitude limit cycles because of the finite reslution of the jets and there may be a similar effect on the space station so you may have small angular rates superposed on the local vertical rate.

Carpenter: Yes, the local vertical is going to be at the torque equilibrium attitude.

Stan Carroll, NASA/Marshall Space Flight Center: That is basically why that tube in the X direction is going to close up on you too is because the angular rate in pitch. So you won't have an empty tube sitting on the dead band. It depends on the dead band and the control rate.